VERIFICATION OF A TRANSLATION

I, Henry M. Feiereisen, having a place of business at 350 Fifth Avenue, Suite 4714, New York, N.Y. 10118, depose and state that:

1. I am familiar with the English and German languages.

2. I have read the attached German language priority document no. 199 28 870.4

3. The hereto attached English language text is an accurate translation thereof.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issuing thereon.

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The attached pieces are a true and accurate copy of the original documents of this patent application.

Munich, 27 July 2002
German Patent and Trademark Office
The Commissioner
On behalf of

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Single Screw Extruder

The present invention relates to a single screw extruder with a barrier screw and a barrel in which the barrier screw is rotatably mounted and which includes at least a longitudinal feed zone section and a longitudinal melting zone section. The invention further relates to a method for extruding a plastic material using such a single screw extruder.

Such single screw extruders are generally known. They typically include an extruder plasticizing barrel in which a screw is rotatably mounted. A powdered or granulated starting material (with stabilizers, slip additives, optionally thermoplastic materials with added fillers and dyes) is fed at one end of the barrel and transported by the rotating screw through the barrel to a so-called die or female mold located at the opposite end. First, the starting material is transported through the so-called feed zone for compaction. The feed zone is followed by a melting zone or plasticizing zone in which the starting material is melted by friction on the interior surface of the barrel. The melting process may be aided - particularly when starting up the extruder - by heating the outside of the barrel with (primarily electric) heating elements. Depending on the application, the melting zone is followed by a homogenizing zone and a shaping zone, where the plasticized material is prepared for further processing.

In recent years, single screw extruders based on the so-called barrier screw concept have gained acceptance as a consequence of their efficiency. An additional flight divides the screw channel of a so-called barrier screw into a solid

matter channel and a melt channel. Compared with the main flight known from conventional screws, the smaller size barrier flight allows melt to flow in the transverse direction from the solid matter channel into the melt channel. The cross section of the melt channel increases downstream, whereas the cross section of the solid matter channel continuously decreases downstream, so as to maintain the desired feed action of the screw. The so-called barrier zone particularly improves the heat transfer from the barrel and the screw surface to the granules that have not yet melted.

Although this barrier screw concept has been proven practical for many applications, there is still a need to increase the performance of a single screw extruder with a barrier screw, while keeping the design as simple as possible.

It is therefore an object of the present invention to improve a single screw extruder based on the barrier screw concept so as to increase its performance, in particular the throughput rate and the pressure build-up capability as well as the melting efficiency.

The object underlying the present invention is attained by a single screw extruder of the aforementioned type by providing the interior wall of the barrel with at least one longitudinal groove in the region of the longitudinal melting zone section.

The throughput rate can be significantly improved over conventional barrier screw extruders by combining a barrier screw with a barrel having at least one groove in the melting zone. This is due in particular to the improved melting process of the starting material. This is essentially caused by the fact that solid matter gets "hooked" in the groove and hence enters the melt channel only in small portions. Advantageously, the heat transfer is also substantially improved, since the inner barrel wall comes in contact with solid matter in the region of the grooves. In conventional barrels having a smooth interior wall, the melt acts as a thermal

barrier, or at least reduces the heat transfer from the interior wall of the barrel to the inside.

The aforementioned improvement of the melting process and the heat transfer allows an increase in the throughput for the same rotation speed, without adding complexity to the design. With conventional single screw extruders, the throughput rate could only be increased by increasing the length of the melting zone and/or the rotation speed of the screw. However, a greater rotation speed caused the melt in the extruder to become hotter in an undesired manner so that damage to the starting material could be encountered. The melt also required more cooling afterwards which again added complexity to the design.

However, the single screw extruder according to the present invention does not require additional design measures. The object of the present invention is therefore fully attained.

In addition to the aforementioned advantages, the single screw extruder with barrier screw according to the present invention advantageously also improves the pressure build-up capability. Unlike with conventional single screw extruders, it is no longer necessary to generate a very high pressure in the so-called feed zone to ensure that a predetermined lower pressure is maintained at the end of the single screw extruder. With the single screw extruder of the present invention, the pressure between the feed zone and the melting zone can be significantly reduced. This reduces wear on the screw in the transition region between the feed zone and the melting zone because lower pressures are applied.

The reduced pressure in the region of the feed zone allows a simpler construction of the feed zone, and eliminates cooling requirements for "heat separation" from the heated melting zone. Advantageously, the feed zone and the melting zone may therefore be fabricated as a single piece.

According to a preferred further development of the invention, the groove has the shape of a helix, whereby the helix lead angle is preferably approximately 30° to 70°.

It has been shown that this design of the groove provides optimum results particularly with respect to the feed process and the pressure build-up, without adversely affecting the melting process and the homogeneity of the melt, respectively.

According to a preferred further development, the barrel includes several grooves, which are spaced in the circumferential direction and which extend preferably parallel to the longitudinal axis of the barrel.

Advantageously, these grooves can be more easily incorporated than helical grooves.

According to another preferred further development, the width and/or the depth of the groove vary in the longitudinal direction, whereby the depth of the grooves preferably decreases towards the downstream end of the melting zone section, preferably to zero.

According to another preferred further development of the invention, at least one groove, extending parallel to the longitudinal axis or helically, can also be provided on the inner wall of the barrel in the region of the feed zone section. Preferably, in the region of the feed zone section, this groove ends smoothly, without transition, in the groove in the region of the melting zone section. Preferably, both grooves have the same lead angle.

This has the advantage that the groove extends continuously without discontinuity along the feed zone and melting zone, thereby further improving the throughput and the pressure build-up.

According to a preferred further development, the barrel is formed in one piece and preferably has a constant inside diameter. These measures advantageously eliminate the need for the conventional, technically complex separation into a feed zone with a cooled grooved bushing and a heated melting zone. In this way, manufacturing costs can be reduced. Moreover, the feed zone may not require cooling due to the good transport efficiency of the overall system, thereby reducing operating expenses.

According to another preferred further development, the barrier screw is formed with two or more pairs of channels, creating two or more solid matter channels and two or more melt channels.

This can advantageously improve the melting efficiency of the single screw extruder compared to the barrier screw with a single channel pair. Moreover, the abrasive wear on the main flight of the screw can then also be minimized.

The object underlying the present invention is also attained by a method of the aforementioned type which is characterized in that a defined quantity of solid plastic material (solid matter) is transported from the solid matter channel into the melt channel in the region of the melting zone. Preferably, the solid matter is transported from the solid matter channel into the melt channel at predefined locations along the barrel. Especially preferred is a transport of the predefined quantity of solid matter by the prevailing pressure differential between solid matter channel and melt channel.

Further advantages and configurations of the invention will be apparent from the following description and the drawings.

It will be understood that the aforedescribed features and the features to be explained hereinafter can be used not only in the respectively indicated combination, but also in other combinations or alone, without departing from the scope of the present invention.

An exemplary embodiment of the invention will now be described in more detail with reference to the drawings. It is shown in:

Fig. 1a a schematic sectional view of a single screw extruder according to a first embodiment;

Fig. 1b a schematic sectional view of a portion of a single screw extruder according to a second embodiment;

Fig. 2 a schematic illustration of a barrier screw;

Fig. 3 a schematic longitudinal section of the extruder in the region of the melting zone;

Fig. 4a a schematic cross section of the barrier screw in a two-channel design; and

Fig. 4b a schematic illustration of a portion of the interior wall of the barrel.

In Fig. 1a, a single screw extruder for extruding a plastic material is designated with the reference symbol 10. The single screw extruder 10 (hereinafter referred to as extruder for sake of simplicity) includes a tubular barrel 11 which in the

illustrated embodiment is composed of three individual tubular barrel structures 12, 14, 16. The individual structures 12, 14, 16 are respectively connected by a flange 17.

The barrel 11 is divided into a plurality of functional longitudinal sections, namely a charging zone 21 followed by a feed zone 22, a melting zone 23, a homogenizing zone 24, and finally a shaping zone 25. In Fig. 1a, the charging zone 21 forms the right end of the barrel 11, and the shaping zone 25 forms the left end of the barrel 11.

A screw 30 is coaxially and rotatably mounted inside the barrel 11. For ease of depiction, neither the screw drive nor the screw bearings are shown. Moreover, for ease of depiction, the illustration also does not show that the screw of the present invention is configured as barrier screw. The barrier screw will hereinafter be described in more detail. The screw 30 extends from the shank of the screw and the charging zone 21 to the end of the homogenizing zone 24. An opening 27, which provides a connection from outside into the interior space of the barrel 11, is disposed in the region of the charging zone 21 of the assembly 12 of barrel 11. A funnel 28 is mounted on the opening 27 to improve feeding of starting material.

Fig. 1a further shows that the structure 12 includes an inner bushing 32 which is inserted into the tubular structure 12. The interior surface of the bushing 32 facing the screw 30 includes axially extending grooves. In Fig. 1a, two of these grooves are designated with reference numeral 33. Typically, the bushing 32 includes a plurality of axial grooves which are evenly spaced from one another in circumferential direction. The grooves 33 have a maximum depth in the region of the charging zone 21, with the depth typically decreasing continuously in the transport direction. The groove depth is generally zero at the end of the feed zone 22.

The bushing 32 is surrounded by ring-shaped or helically-shaped cooling channels 35, whereby both the coolant inlet and the coolant outlet have been omitted from the figure for ease of depiction.

The tubular barrel structure 14 is surrounded by schematically illustrated heating elements 38, wherein the heating elements 38 extend along the entire length of this structure so that both the melting zone 23 and the homogenizing zone 24 can be heated by such heating elements 38. In the aforementioned embodiment, several heating elements 38 are arranged in succession in the longitudinal direction. A further heating element 38 also surrounds the third structure 16 in the region of the shaping zone 25. The heating element can also be provided with cooling elements for removing optional excess friction heat produced at higher rotation speeds of the screw.

In the embodiment of the extruder 10 shown in Fig. 1a, both structures 12 and 14 are connected with each other via a flange 17. Of course, both structures 12, 14 may also be combined into a single structure 13, eliminating the need for a flange connection. Fig. 1b shows a partial view of this less complex embodiment of an extruder 10'. As can be seen, not only is the structure 13 implemented as a single piece, but the grooved bushing 32 and a cooling in the form of cooling channels 35 are also eliminated. The part of the extruder 10' that is not shown corresponds to the part of extruder 10 of Fig. 1a. Moreover, in both Figs. 1a, 1b, same elements are designated with identical reference numerals and will therefore not be described again.

Such an extruder 10 and 10', respectively, generally performs the following functions:

Mostly granulated starting material of plastic is fed into the funnel 28 and enters thereafter the charging zone 21 through the opening 27. The starting material is

transported -- in Fig. 1 to the left-hand side – by respective rotation of the screw 30. The starting material is then compacted in the feed zone 22 by a respective configuration of the screw 30 and the grooves 33. This region must be cooled via the cooling channels 35 due to the pressure build-up which is enhanced by the grooves 33. After passing the feed zone 22, the compacted starting material (solid matter) enters the melting zone 23 where the solid matter is melted through friction of the solid matter on the interior wall of the barrel and/or by heat supplied by the heating elements 38. At the end of the melting zone 23, the melt enters the homogenizing zone 24 where a suitable shape of the screw 30 melts any possible remaining solid matter particles. Further, additives may be effectively admixed in this zone. The homogenized melt finally enters the shaping zone 25 where the melt is conditioned for further processing.

The throughput rate of the extruder 10 substantially depends on the rotation speed of the screw 30. Throughput could therefore advantageously be increased by increasing the rotation speed. However, the problem then arises that the degree of homogeneity of the melt at the end of the melting zone 23 deteriorates because many solid matter particles have passed through the melting zone 23 too fast. Moreover, the melt film produced at the interior surface of the barrel acts as a heat insulator which prevents an effective heat transfer from the heating/cooling elements 38 to the solid matter.

The efficiency is significantly improved compared to a conventional screw by a so-called barrier screw, which is schematically illustrated in Fig. 2 and which is designated as screw 30 in the extruder 10 of Fig. 1a. This type of barrier screw is generally known, so that its detailed structure and function need not be described in detail. The mode of operation of such a barrier screw is disclosed, for example, in "Der Einschnecken-Extruder - Grundlagen und Systemoptimierung" ["*The single Screw Extruder - Basics and System Optimization*"], VDI-Verlag 1997.

Fig. 2 shows a barrier screw designated with the reference numeral 40. The barrier screw 40 includes several longitudinal sections, wherein only the longitudinal section designated with reference numeral 42 is relevant for the following description. This longitudinal section 42 is located within the melting zone 23 of the barrel 11 when the barrier screw 40 is installed. The barrier screw 40 is characterized in that it includes a so-called barrier flight 46 in addition to the primary or main flight 44. The main flight 44 in conjunction with the downstream barrier flight 46 forms a melt channel 48, and in conjunction with the upstream main flight 44 a solid matter channel 49. As can also be seen in Fig. 2, the width of the solid matter channel decreases towards the downstream end of the longitudinal section 42, whereas the width of the melt channel 48 increases. The particular mode of operation of the barrier screw 40 is based, in particular, on the fact that the gap disposed between the interior wall of the barrel and the main flight is smaller than the gap between the barrier flight 46 and the interior wall of the barrel. This can be seen clearly in Fig. 4a which shows a cross section of a barrier screw with two pairs of channels. Fig. 4a also shows clearly the two diametrically opposed main flights 44 and the two also diametrically opposed barrier flights 46. In Fig. 4a, the gap between the main flight 44 and the interior wall 50 of the barrel 11 (blocking gap) is designated with δ_s and the gap between the barrier flight 46 and the interior wall 50 (barrier gap) with δ_0. δ_s of barrier screws is generally smaller than δ_0. As already mentioned above, when viewed in rotation direction, the solid matter channel 49 is formed between a barrier flight 46 and a main flight 44, and the melt channel 48 is formed between a main flight 44 and a following barrier flight 46. Two of such solid matter channels 49 and two melt channels 48 are included in the illustrated embodiment with two channel pairs.

According to the invention, grooves 52 are formed in the interior wall 50 of the barrel 11 in the region of the melting zone 23. In the exemplary embodiment shown in Fig. 4a, a total of eight grooves 52 are provided which extend in axial

direction and which are uniformly spaced in the circumferential direction of the barrel. Further, the grooves have a rectangular cross section. Especially advantageous is however a configuration of the grooves 52 without sharp edges. Fig. 4a shows an exemplary single groove 52' having rounded edges. It is, of course, also conceivable and advantageous to provide one or more helical grooves 52', as illustrated in Fig. 4b, instead of several of axial grooves 52.

The width of the grooves 52 is substantially of a same order of magnitude as the width of the main flights 44 and the barrier flights 46, respectively. The depth of the grooves 52 should be selected dependent on the application, and attention must be paid that the depth is not too large, since otherwise the functionality may be impaired. Both the groove depth and the groove width can vary in the longitudinal direction of the barrel 11, with the groove depth in the downstream end region of the melting zone 23 preferably decreasing to almost zero. This conical taper of the grooves 52 has proven to be particularly advantageous.

Fig. 3 shows again schematically a longitudinal cross-section of the barrel 11 in the region of the melting zone 23. The barrier screw 40 includes two helical main flights 44 and spaced therefrom two likewise helical barrier flights 46. As already mentioned above, a main flight 44 and a barrier flight 46 together demarcate the melt channel 48 and the solid matter channel 49, respectively. Fig. 3 shows a total of three grooves 52, each having a groove depth h_N.

The following process takes place during the operation of the barrier screw 40 in the barrel section 23 provided with grooves 52:

The screw portion in the feed zone 22 presses the solid matter into the solid matter channel 49 of the barrier screw 40 in the melting zone 23. The solid matter in the solid matter channel 49 is hence under pressure, which for the desired high throughput is generally higher than the pressure in the melt channel 48. As a

consequence of the pressure differential between the solid matter channel 49 and the melt channel 48, the solid matter attempts to enter the melt channel 48. In view of the selected gap between the flights 46, 44 and the interior wall 50, only the melted solid matter enters the melt channel 48 across the barrier flight 46 as a melt. The gap between the main flight 44 and the interior wall 50 is too small even for melt. Because according to the present invention the interior wall 50 of the barrel 11 includes grooves 52, the gap between the interior wall and the main flight 44 and the barrier flight 46, respectively, increases, when the respective flight sweeps over the groove 52. Consequently, the solid matter pressed into the grooves 52 enters the melt channel 48 in "portions." For example, the symbol "A" in Fig. 3 indicates that solid matter is pressed into the groove 52 displacing the melt residing in the groove. The displaced melt flows into the melt channel 48, as indicated by the symbol "B". In addition, the mixture of solid matter and melt residing in the grooves 52 is pressed into the melt channel 48, as indicated by the symbol "C". These "small portions" of solid matter are almost entirely melted in the melt channel 48. Any inhomogeneities remaining at the end of the melting zone 23 are eliminated in the following homogenizing zone 24. However, this transfer of solid matter allows the pressure in the solid matter channel to be significantly reduced, thereby reducing the abrasive wear on the screw 30 and the barrel 11.

Because solid matter enters the melt channel 48 early on in small defined portions, the melt and the small solid matter particles can also be mixed early so that, on the one hand, the resulting temperature of the melt can advantageously be kept low even at a higher rotation speeds and, on the other hand, the homogeneity of the melt can be ensured.

In summary, the grooves in the interior wall of the barrel according to the invention prevent a deterioration of the homogeneity and heat transfer with increasing throughput rate. The rotation speed of the screw can therefore be increased without requiring additional design measures, such as extension of the melting

zone, or increased heating, or cooling of the barrel. It has also been observed that, in particular, the grooves of extruders with a barrier screw show the aforementioned advantageous effects.

Claims

1. Single screw extruder with a barrier screw (40) and a barrel (11), in which the barrier screw (40) is rotatably supported and which comprises at least one longitudinal feed zone section (21, 22) and a longitudinal melting zone section (23), characterized in that the barrel (11) includes on its inner wall (50) in the region of the longitudinal melting zone section (23) at least one groove (52) extending in a longitudinal direction.

2. Single screw extruder according to claim 1, characterized in that the groove (52) extends helically.

3. Single screw extruder according to claim 2, characterized in that the lead angle of the groove (52) is approximately 30° - 70°.

4. Single screw extruder according to one of the preceding claims, characterized in that a plurality of grooves (52) are provided which are spaced apart in a circumferential direction of the barrel (11).

5. Single screw extruder according to one of the preceding claims, characterized in that the width and/or depth (h_N) of the groove(s) (52) vary in the longitudinal direction.

6. Single screw extruder according to claim 5, characterized in that the depth (h_N) of the groove (52) decreases towards the downstream end of the melting zone section (23), preferably to zero.

7. Single screw extruder according to one of the preceding claims, characterized in that at least one groove (33) is provided on the interior wall (50) of the barrel in the region of the feed zone section (22) and extends parallel to the longitudinal axis or helically.

8. Single screw extruder according to claim 7, characterized in that the groove (33) in the region of the feed zone section (22) ends, without transition, in the groove in the region of the melting zone (23).

9. Single screw extruder according to claim 8, characterized in that the groove (33) and the groove (52) have the same lead angle.

10. Single screw extruder according to one of the preceding claims, characterized in that the lead angle of the groove (52) is variable along the longitudinal axis.

11. Single screw extruder according to one of the preceding claims, characterized in that the barrel (11) is formed as a single piece.

12. Single screw extruder according to claim 11, characterized in that the melting zone section (23) is implemented as a cylindrical tube and the feed zone section is implemented as a grooved bushing (32, 33).

13. Single screw extruder according to one of the preceding claims, characterized in that the barrel (11) comprises an interior space with a constant diameter, when viewed in the longitudinal direction.

14. Single screw extruder according to one of the preceding claims, characterized in that the barrier screw comprises two or more channel pairs which form two or more solid matter channels (49) and two or more melt channels (48).

15. Method for extruding plastic material with a single screw extruder (10) which includes a barrier screw (40) rotatably supported in a barrel (11), wherein the extruder (10) includes a feed zone (21, 22) and a melting zone (23) and wherein the barrier screw (40) includes at least a solid matter channel (49) and a melt channel (48), characterized in that in the region of the melting zone (23) a defined quantity of solid plastic material (solid matter) is transported from the solid matter channel (49) into the melt channel (48).

16. Method according to claim 15, characterized in that the solid matter is transported at defined locations along the barrel (11) from the solid matter channel (49) into the melt channel (48).

17. Method according to claim 15 or 16, characterized in that the defined quantity of solid matter is transported largely by the existing pressure difference between the solid matter channel and the melt channel.